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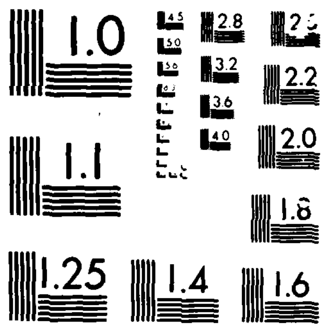

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AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

STRUCTURES REPORT 418

THE AUSTRALIAN IMPLEMENTATION OF AMDAR/ACARS AND THE USE OF DERIVED EQUIVALENT GUST VELOCITY AS A TURBULENCE INDICATOR

by

Douglas J. Sherman

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SUMMARY

AMDAR is a system of measuring wind speed, wind direction, air temperature and an indication of turbulence from INS equipped transport aircraft in flight. These data are transmitted by radio to the meteorological data system.

This report outlines the Australian AMDAR system presently coming into service on the Boeing 767 aircraft in the Ansett fleet. The data are telemetered using ACARS and the SITA/AIRCOM network of ground stations.

Particular attention is paid to the indicator of turbulence. Because an aircraft flying through a given gust may encounter very different vertical accelerations depending on aircraft mass, airspeed and altitude, it is proposed that the AMDAR system compute the derived equivalent gust velocity from the aircraft acceleration and other parameters, and that this be used as an indicator of turbulence. Such an indicator has the additional advantage that it is more use for climatological studies of turbulence occurrence than simpler indicators such as the aircraft vertical acceleration. Severe turbulence corresponds to derived equivalent gust velocities in excess of 9 m/s.

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CONTENTS

LIST OF SYMBOLS

a	- Lift curve slope $dC_L/d\alpha$
A	- Parameter defined by equations 2.8 and 2.9
A_{110}	- Value of A for aircraft of mass 110 tonne
A_m	- Value of A for aircraft of mass m tonne
$A_{0.8}$	- Value of A for aircraft flying at Mach 0.8
A_M	- Value of A for aircraft flying at Mach M
$b_1,\ldots,b_5$	- Parameters in equations 3.7, A4.3
c	- Mean aerodynamic chord
c_p	- Specific heat at constant pressure
c_v	- Specific heat at constant volume
C_L	- Lift coefficient
F	- Gust alleviation factor
g	- Vertical acceleration due to gravity (9.8 m/s/s)
h	- Enthalpy
H	- Aircraft altitude in thousands of feet
L	- Lift force
m	- Aircraft mass
M	- Mach number
n	- Vertical acceleration of aircraft in units of g. ($n = 1g$ in straight and level flight. Hence $\Delta n = n - 1$ denotes additional acceleration due to gust.)
p	- Pressure
p_0	- Air pressure at sea level
p_t	- Air pressure at a stagnation point
q	- Dynamic pressure (see equation A2.1)
R	- Gas constant
S	- Wing area
T	- Temperature
T_t	- Air temperature at a stagnation point
u	- Internal energy per unit mass
U	- Vertical gust velocity
U_{de}	- Derived equivalent gust velocity
v	- Specific volume
V	- Velocity
V_a	- Speed of sound
V_{a0}	- Speed of sound at sea level
V_c	- Calibrated air speed
V_e	- Equivalent air speed
V_t	- True air speed
W	- Aircraft weight ($W = mg$)
z	- Height
α	- Angle of attack
γ	- Ratio of specific heats c_p/c_v
μ_g	- Aircraft mass ratio $\mu_g = \frac{2\times(W/S)}{\rho c a g}$
ρ	- Air density
ρ_0	- Air density at sea level (1.225 kg/cubic metre)
ρ_t	- Air density at a stagnation point
σ	- Density ratio ρ/ρ_0
σ_x	- Denotes the standard deviation of any quantity, x

THE AUSTRALIAN IMPLEMENTATION OF AMDAR/ACARS AND THE USE OF DERIVED EQUIVALENT GUST VELOCITY AS A TURBULENCE INDICATOR

1. INTRODUCTION

AMDAR (Aircraft Meteorological Data Relay) is a system of measuring air temperature and wind velocity from large transport aircraft equipped with Inertial Navigation Systems and transmitting these data, by radio, into the World Weather Watch network. The system is outlined in Appendix 1.

After some years experience with a prototype system (see Sparkman, Giraytys and Smidt, 1981) it has become apparent that certain additional features are desirable. One of these is the ability to report turbulence in addition to wind velocity. The basic indicator of turbulence is the vertical acceleration of the aircraft measured at (or near) the centre of gravity, and an early proposal was to report a turbulence parameter generated from accelerometer data and formatted according to a slight modification of the ICAO(1970) recommendations for pilot reports (PIREPS). In this proposal turbulence is simply divided into four categories depending on the aircraft vertical acceleration.

Measured Peak Acceleration Deviation	Turbulence Category
0 - 0.2g	Nil
0.2g - 0.5g	Light
0.5g - 1.0g	Heavy
Over 1.0g	Severe

It is recognised, however, that this categorisation was chosen for PIREPS because of limitations on the time and amount of information available to a pilot making a report. A computerised data acquisition system is capable of reporting a much more sophisticated index of turbulence.

In discussion with the Australian Bureau of Meteorology, this author has recommended that a well recognised parameter in aircraft design, the derived equivalent gust velocity, be used as a measure of turbulence severity. This is because one of the problems of using aircraft acceleration alone as a measure of turbulence is that a given gust in the atmosphere will cause quite different accelerations to two different aircraft. To a first order approximation, the acceleration varies directly with the aircraft's airspeed and inversely with the aircraft's weight. The derived equivalent gust velocity is a simple measure of the severity of the actual atmospheric gust strength which can be calculated from the parameters available on the aircraft's integrated data system. The values of derived equivalent gust velocity computed from encounters by two different aircraft with the same gust are comparable,* so this is a suitable measure for climatological studies of the occurrence of atmospheric turbulence.

* Experimental comparisons are difficult. If two aircraft penetrate the same patch of turbulence they must have significant lateral or time separations, so they only experience moderately similar turbulence. If flown close behind each other the wake turbulence of the leading aircraft and manoeuvres by the aircraft following in formation will be disturbing factors. Curran (1971) has shown comparable statistical counts for a Canberra and a Vulcan flying together in turbulence. Strom and Weathermon (1963) have reported on flights of a B66B, equipped with a gust probe (to measure actual gust velocity components), through high altitude turbulence (around 30 000 ft). They present time history graphs of derived equivalent gust velocity and the three turbulent gust components. The shapes of the time history graphs of derived equivalent gust velocity and of true gust vertical velocity are different, as expected because of the filtering effect

2. THE GUST RESPONSE OF AN AIRCRAFT

Conventional gust design analysis of an aircraft is specified in terms of a derived equivalent gust velocity. (See ESDU(1979), section 2, or JAR(1983), section 25.341.) This velocity is a measure of the vertical gust velocity which would, at sea level, induce the same vertical acceleration as the peak acceleration encountered by an aircraft flying through a patch of turbulence. When an aircraft flying at speed V_e encounters a vertical gust of magnitude U, there is an increase in the angle of incidence,

$$\Delta\alpha = U/V_e \tag{2.1}$$

Since the lift force acting on an aircraft flying at sea level is

$$L = C_L \times \frac{1}{2}\rho_0 V_e^2 S \tag{2.2}$$

the gust will, if transient aerodynamic effects are ignored, cause an additional vertical force of

$$\begin{aligned}\Delta L &= \frac{dC_L}{d\alpha} \times \Delta\alpha \times \frac{1}{2}\rho_0 V_e^2 S \\ &= a \times \frac{1}{2}\rho_0 U V_e S\end{aligned} \tag{2.3}$$

where

$$a = \frac{dC_L}{d\alpha}$$

On an aircraft of mass m, this will cause a consequent additional vertical acceleration, measured in units of g, of

$$\Delta n = \frac{a\frac{1}{2}\rho_0 U V_e S}{mg} \tag{2.4}$$

If transient aerodynamic effects are included, this vertical acceleration will be reduced by the gust alleviation factor, F,

$$\Delta n = \frac{F \times a \times \frac{1}{2}\rho_0 U V_e S}{mg} \tag{2.5}$$

American practice, as exemplified in JAR, is to use the value of F appropriate to a gust length of 12.5 chords. In this case F is given by the simple empirical formula developed originally by Houbolt and subsequently reported by Pratt and Walker(1954):

$$F = \frac{0.88 \times \mu_g}{5.3 + \mu_g} \tag{2.6}$$

where

$$\mu_g = \frac{2 \times (W/S)}{\rho c a g} \tag{2.7}$$

This formula does not make any allowance for Mach number effects. British practice, as exemplified in the ESDU data item, is to use a value of F appropriate to a gust length of 100 ft. Allowance is made for Mach number effects on the alleviation factor, but the resultant calculations are very complex, so ESDU give a set of graphs from which to compute F. The quantitative difference between the two approaches is quite small in most cases. Actual figures for the Boeing 767 are shown later in this report. (See Tables A3.1 to A3.5.) The differences are in most cases less than 5%, and at the higher Mach numbers, encountered in all normal flying, other than take-off and landing, the differences are less than 1%. The derived equivalent gust velocity is thus given by

$$U_{de} = \frac{2mg/S}{Fa\rho_0 V_e} \times \Delta n$$

so that

of the aircraft, but the peak values are generally similar when allowance is made for the air density ratio.

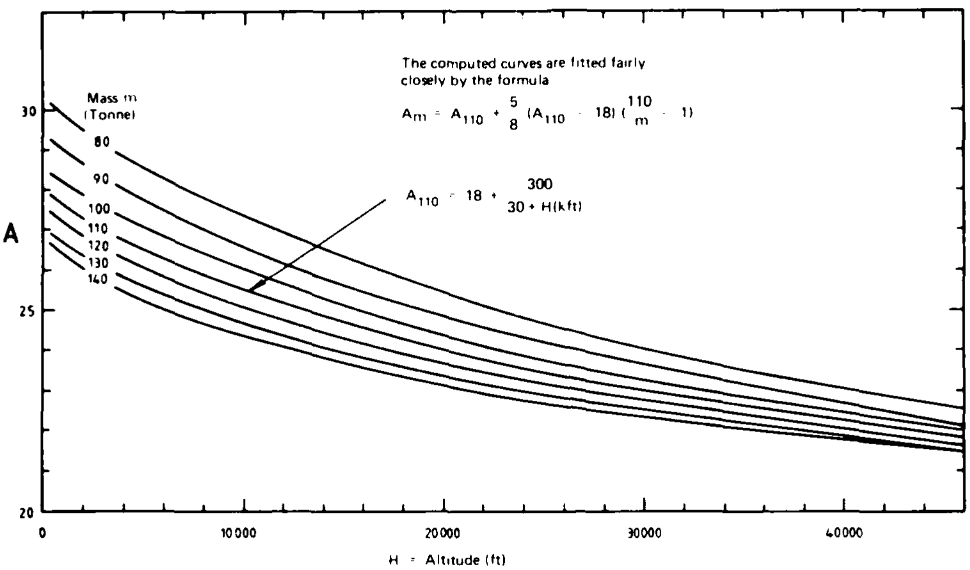

FIG. 1 VALUE OF PARAMETER 'A' FOR TYPICAL ALTITUDE/SPEED COMBINATIONS

$$U_{de} = A \times \frac{m}{V_c} \times \Delta n \tag{2.8}$$

where

$$A = \frac{2g}{Fa\rho_0 S} \times \frac{V_c}{V_e}$$

is a weak function of aircraft mass, altitude and Mach number. (See Figures 1 and 2.)

If m is measured in tonne and V_c in knot, this becomes

$$A = \frac{2g}{Fa\rho_0 S} \times \frac{V_c}{V_e} \times \frac{1000}{0.514} \tag{2.9}$$

Equation 2.8 is written in terms of calibrated air speed, V_c, rather than equivalent air speed, V_e, because the calibrated airspeed is available to the flight data system. The two quantities are fairly similar (see Appendix 2), differing by about 6% at cruise speed and altitude.

U_{de} values are likely to be in the range 0 to 15 m/s. JAR 25.341 specifies a limit load** corresponding, at cruise speed, to a gust of 15 m/s (50 ft/s) up to an altitude of 20000 ft and then reducing linearly to 7.5 m/s (25 ft/s) at 50000 ft. Ultimate loads are required to be at least 1.5 times the limit load. Such loads do occasionally occur. On 14 October 1974 a Boeing 727 flying from Perth to Adelaide struck severe turbulence in thin stratus cloud at 35000 ft. (See the Adelaide Advertiser of 15 October 1974.) A bracket of three seats at the rear of the plane was ripped from its mountings and eleven passengers were injured. The peak derived equivalent gust velocity was calculated by one investigator to be 29.9 m/s!

** Limit load is the maximum load the aircraft structure can support without detrimental permanent deformation. Hoblit et al(1966) have shown that for three benchmark aircraft considered to perform satisfactorily (The Lockheed 749 Constellation, Lockheed 188 Electra and Boeing 720B) the limit gust load is expected to occur once in 50000 hours flying.

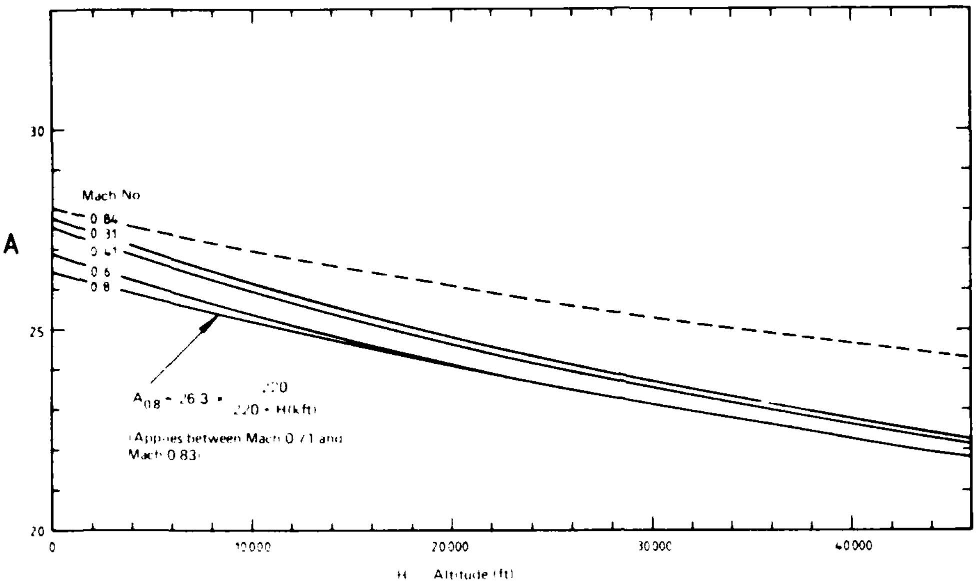

FIG. 2 VALUE OF PARAMETER 'A' FOR FLIGHT AT FIXED MACH NUMBERS

3. PRACTICAL APPLICATION WITH SPECIAL REFERENCE TO THE B767

Three different approaches have been considered for the on-board computation of the parameter A. A deliberate policy in all three approaches has been to eschew function evaluation and square roots so as to simplify the implementation on a small computer. The results of computations relevant to all three approaches are given in Appendix 3.

The first, and simplest, approach considers typical altitude/airspeed combinations (see Table A3.1) and a typical mass of 110 tonne. The value of A is approximated closely by the formula (see Fig. 1)

$$A_{110} = 18 + \frac{300}{30 + H} \tag{3.1}$$

where H is the height in thousands of feet, and A $(= A_{110})$ is given by equation 2.9. If the aircraft mass is limited to the range 90 to 125 tonne, the difference between equation 3.1 and the more accurately computed value is generally less than 5%.

The second, more complex, approach allows for the possibility that the altitude/airspeed combinations may differ considerably from those shown in Table A3.1, so that allowance may need to be made for Mach number effects. Table A3.3 and Fig. 2 show the results of calculations for flight at several different Mach numbers. For Mach numbers above 0.71, the value of A is almost independent of Mach number.† At lower Mach numbers the value of A rises somewhat. The curve shown in Fig. 2, for Mach numbers around 0.8 and an aircraft mass of 110 tonne, is fitted by

† At Mach numbers above 0.83, A increases rapidly as flow around the aircraft becomes increasingly transonic. In this flow regime the computed parameters tabulated in the Appendix are probably very inaccurate because they have been calculated with a general purpose program not adjusted to fit flight trial results from the B767. However this is probably not important, as high Mach number flight will generally be avoided because of the possible onset of Mach buffet. Therefore little account has been taken of this increase which is shown in Fig. 2 but only poorly represented in equations 3.4 and 3.7.

$$A_{0.8} = A_{0,ref} \times \frac{220}{220 + H} \tag{3.2}$$

where

$$A_{0,ref} = 26.2 \tag{3.3}$$

for an aircraft mass of 110 tonne, and for another aircraft mass and lower Mach number there are small corrections given by,

$$A_0 = A_{0,ref} \times \left[1 + 0.25\left(\frac{110}{m} - 1\right)\right] + \left[5 - 0.1A_{0,ref}\frac{H}{H+5}\right] \times \left|\frac{1}{M^4 + 1} - \frac{1}{0.75^4 + 1}\right| \tag{3.4}$$

The general equation for A is

$$A = A_0 \times \frac{220(\frac{m}{110})}{220(\frac{m}{110}) + H} \tag{3.5}$$

The last column of Tables A3.1 to A3.4 shows the value of A estimated by this equation. There is close agreement (almost always within 2%) with the computed values of A in the penultimate column.

The third approach is most closely related to the direct evaluation of A from equation 2.9. It involves more sub-formulae and parameters than the second approach.

To evaluate μ_g (equation 2.7) the air density ρ is needed. This may be determined by any of the usual methods, or the following empirical formula may be used,

$$\frac{\rho}{\rho_0} = \frac{1}{1 + 38.4 \times 10^{-3}H - 576 \times 10^{-6}H^2 + 39.64 \times 10^{-6}H^3} \tag{3.6}$$

where $\rho_0 = 1.225\,\mathrm{kg/m^3}$ and H is the altitude in thousands of feet. This formula is accurate within $2\frac{1}{2}$% and generally within 1% up to 50 000 ft.

The lift curve slope is needed for both equations 2.7 and 2.9. It may be estimated by the following equation,

$$a = (b_1 + b_2M^2) \times \left\{1 - b_4 + b_4\left[1 - b_5\left(\frac{M}{b_3}\right)^{16} - (1 - b_5)\left(\frac{M}{b_3}\right)^{64}\right]^2\right\} \tag{3.7}$$

For the Boeing 767 the parameters $b_1, \ldots, b_5$ are given by $b_1 = 5.24$, $b_2 = 2.0$, $b_3 = 0.9$, $b_4 = 0.6$, and $b_5 = 0.1$. The wing area, S, and the mean aerodynamic chord, c, of the 767 are $S = 291$ square metre, and $c = 7.2$ metre. The values of all these parameters for several other aircraft, including some of the present ASDAR equipped aircraft, are tabulated in Appendix 4.

The gust alleviation factor, F, may be computed from equation 2.6 and the remaining factor in equation 2.8 may be computed from the empirical equation

$$\frac{V_c}{V_e} = 1 + \frac{H(140 - H)}{4000} \times \frac{M^2}{10} \tag{3.8}$$

which fits the data extremely closely at least for $0 \leq H \leq 45\,\mathrm{kft}$ and $0 \leq M \leq 0.95$.

4. ERROR ANALYSIS

The basic equation proposed here is equation 2.8:

$$U_{de} = A \times \frac{m}{V_c} \times \Delta n \tag{4.1}$$

We will consider each parameter in turn.

(i) The value of A, computed by equation 3.5 of the preceding section, is known to within 2% of the more accurately computed value for all practicable flight conditions. If A is computed from equation 2.9 using the empirical relations in section 3 the error will be even less.

(ii) The aircraft mass, m, is known within 3%, and under most conditions within 1% at all times. Passengers are counted and reckoned to have an average mass of 77kg, including carry-on baggage. [There may be up to 211 passengers, giving, with a coefficient of variation of 0.2, a standard deviation of

$$77 \times 0.2 \times \sqrt{211} = 223kg.$$

Three standard deviations is 670kg, less than 1% of the minimum aircraft weight.] Baggage in the hold is reckoned at 13.7kg per piece, and the quantity of fuel metered into the aircraft is known within 1%. A heavy fuel load of 50 000kg thus has an uncertainty of 500kg. Fuel use rate is metered and the reductions in mass are continually fed to the flight data system throughout the flight.

(iii) The calibrated air speed, V_c, is known to a high degree of accuracy. Above 200 knot the error is less than 1 knot. At 100 knot the error is plus or minus 2 knot, and at 60 knot, the error is plus or minus 4 knot.

(iv) The main error in the measurement of vertical acceleration is due to longitudinal displacement between the accelerometer and the centre of gravity of the aircraft. The centre of gravity position varies depending on the loading and fuel state of the aircraft. The Australian Air Navigation Order 103.19 requires that the vertical acceleration sensor be located longitudinally either within the approved centre of gravity limits of the aeroplane, or at a distance forward or aft of these limits that does not exceed 25% of the aeroplane's mean aerodynamic chord (m.a.c.). In the case of the Boeing 767 the centre of gravity is located, on 99% of occasions, between body station 949 inch (15% m.a.c.) and 973 inch (25% m.a.c.), whilst the accelerometer is located at body station 977 inch (26.8% m.a.c.).‡ On most occasions, therefore, the centre of gravity of the aircraft is located within 28 inch (0.7 m) of the accelerometer. An individual gust will excite a pitching motion which may add to or subtract from the peak acceleration recorded by the accelerometer. Data read from the digital flight data recorder on a 767 aircraft in turbulence show peak to peak pitch oscillations of 1.5° to 2° with a period of about 6.5 seconds. This will cause peak to peak acceleration fluctuations 0.7m away from the centre of gravity of 0.002g to 0.0025g. The actual observed accelerometer fluctuations were 0.15g to 0.2g peak to peak. Depending on the actual relative phase of acceleration and pitch, the errors at individual points could be up to 1.2%. These figures are in line with computations of aircraft gust response. Galea(1985) has computed the gust response of an aircraft which is superficially similar to a 727. He found that the ratio of the standard deviation of aircraft vertical acceleration to the standard deviation of vertical gust velocity was $\sigma_{\Delta n}/\sigma_U = 0.0676\ g/m/sec$ if the acceleration was measured at the centre of gravity, and $\sigma_{\Delta n}/\sigma_U = 0.0699$ if the acceleration was measured 1m aft of the centre of gravity. These figures suggest that the average errors in the c.g. acceleration measurement for an accelerometer displacement of 0.7m will be about 2%.

Current technological advances have made it possible to use active control techniques to alleviate the vertical acceleration of an aircraft due to gusts. If implemented, this would raise problems

‡ The mean aerodynamic chord (m.a.c.) has a length of 237.5 inch, and its leading edge is located at body station 913.3 inch.

for *any* index of turbulence based on aircraft vertical acceleration. In private discussions at NASA Langley during January 1982, it was suggested that the autopilot on some "analogue" aircraft might reduce the standard deviation of gust loads by about 20% at the cost of increasing their frequency, also by about 20%. Current research then underway with gust load alleviation at NASA Langley using a system called Dyloflex, was able to reduce the standard deviation of gust loads by up to 40% at selected locations on the aircraft. However gust load alleviation can result in increases in load in other parts of the aircraft, such as the tail, and the structural implications of such effects have to be considered carefully. At present gust alleviation is not installed on the Boeing 767.

Manoeuvres during flight also cause vertical acceleration to the aircraft. In general, the acceleration due to manoeuvres on large passenger aircraft is kept low to minimise discomfort to passengers. Hunter and Fetner(1967) give statistics of manoeuvre accelerations occurring on 727 aircraft in normal service. Acceleration increments rarely exceed 0.3g (about once per two hours, less than one tenth the frequency expected due to gusts). With transport aircraft it is possible to devise algorithms to separate the accelerations due to turbulence from those due to manoeuvres. These algorithms usually amount to filtering the acceleration record with a cut-off frequency of the order of 1 hertz. The low pass signal is due to manoeuvre, the high pass signal due to gust. This requires considerable signal processing capability so has not been proposed at this stage. A more feasible solution in the AMDAR context may simply be to determine whether large peaks are due to turbulence by some "smart" algorithm, probably based on counting level crossings around the large peak.

5. RECOMMENDATION

When an aircraft flies through a given vertical gust, the resultant acceleration of the aircraft depends strongly on the aircraft weight and airspeed. If a measure of the primary vertical gust is reported this will be of more universal application than the consequent aircraft acceleration. Such a measure, which is well recognised in aeronautics and is readily calculated with data available to the Flight Data Acquisition Unit, is called the derived equivalent gust velocity. It is recommended that, in the AMDAR context, derived equivalent gust velocity be computed and used as an indicator of turbulence. This proposal has already been adopted in the Australian B767 implementation described in Appendix 1. Severe turbulence will correspond to derived equivalent gust velocities in excess of about 9m/s.

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APPENDIX 1

A1. THE AIRCRAFT METEOROLOGICAL DATA RELAY (AMDAR) SYSTEM

A1.1 ASDAR

The concept of automatically reporting meteorological data from commercial aircraft through geosynchronous satellites originated during the mid 1970's. The United States provided 17 Aircraft to Satellite Data Relay (ASDAR) systems as part of its contribution to the First GARP Global Experiment (FGGE) special observing programme during 1979. These 17 plus 11 additional systems reporting directly to ground stations over a digital VHF link called ACARS (ARINC Communications Addressing and Reporting System), were evaluated operationally during FGGE. The data from both ASDAR and ACARS were received in real time, exchanged over the Global Telecommunication System (GTS) (of WMO) and used directly in meteorological analyses. At the beginning of 1984 some 5-7 ASDAR systems and all 11 ACARS systems were still providing data as part of the extended operational evaluation. The success of the FGGE evaluation led to the decision to proceed with implementation of an operational system. It is estimated that for a system comprising 100 ASDARs the cost per useful bit of information will be about 0.1 cent (U.S.).

In December 1982, eight members of WMO formed the Consortium for ASDAR Development (CAD). At the beginning of 1984 this consortium had expanded to the following nine members:

Australia
Canada
Germany (Federal Republic of)
Netherlands
New Zealand
Saudi Arabia
Sweden
United Ki ~dom
U.S.A.

The purpose of the CAD is to provide the financial resources needed to make available a flight-certified, commercially available unit for use on B-747, L-1011, and DC-10 aircraft. In September 1983, WMO, acting on behalf of the CAD, signed a contract with GEC-McMichael (U.K.) to complete the development work, obtain all necessary certification, establish a production and maintenance capability and to prepare the necessary installation and operating manuals.

The operational ASDAR will obtain information on atmospheric wind and temperature from the aircraft data systems. Every seven minutes during level flight and more frequently during climb and descent* a set of observations is made. This set contains:

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* Specifically, ASDAR observations are made:

a) During climb - One observation every 10 mbar starting at the surface until ten observations have been made, then
- One observation every 50 mbar to top of climb

b) During cruise - One observation every 7 minutes
- An additional observation will be made if the wind speed is greater than 60 knots and has changed by more than 10 knots since the previous observation.

c) During descent - One observation every 50 mbar between beginning of descent and 700 mbar. Thereafter observations are made every 10 mbar to landing, but only the 50 mbar levels and the last ten observations before landing will be reported. (Data will be lost if power is switched off before the message is sent.)

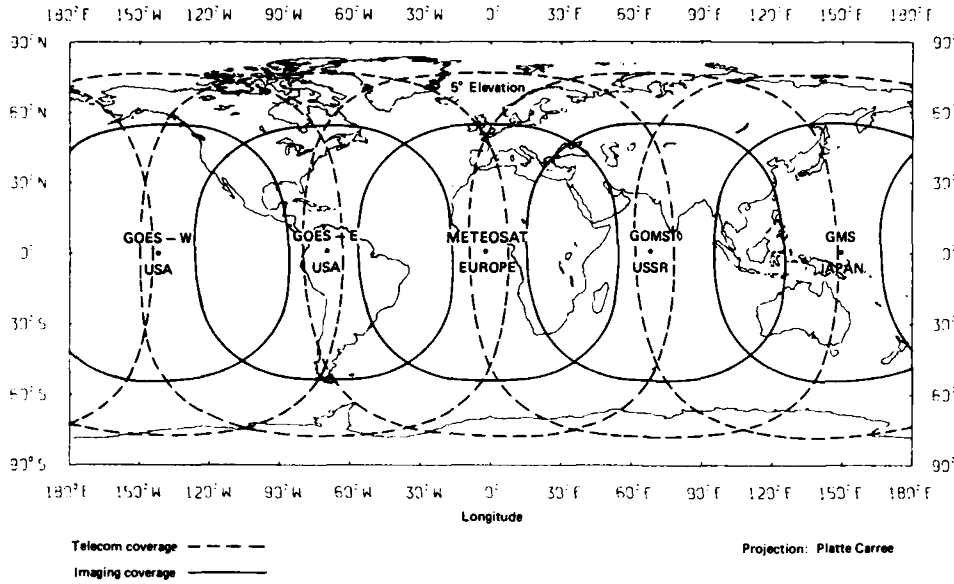

FIG. 3 COVERAGE OF GEOSTATIONARY SATELLITES

Latitude in degrees and minutes,
Longitude in degrees and minutes,
Time in hours and minutes (GMT),
Pressure altitude in feet,
Static air temperature in degrees Celsius,
Wind direction - true North,
Wind speed in knots,
Turbulence,
Humidity (if sensor available).

These sets of observations are not transmitted immediately because of the limited capacity of the international DCP channels. Instead they are stored in on-board memory. Each ASDAR unit is allocated a fixed 1-minute time slot within each hour for data transmission. At hourly intervals the stored observations are transmitted together with an aircraft identifier. These hourly messages are transmitted on UHF from a small (approx 50cm x 60cm x 2cm), low drag, profiled plate antenna mounted on top of the fuselage. The data are received by any Geosynchronous Meteorological Satellite (GMS) within radio range and then relayed on S-band to earth receiving stations. The satellite data system provides world wide coverage between approximately 80° North and 80° South latitudes (see Fig. 3). The data are freely exchanged world wide on the GTS of the World Weather Watch and are available to all forecast centres.

A1.2 ACARS

One of the disadvantages of the ASDAR system is the time delay of up to an hour before observations are transmitted from the aircraft. Wind shear data during landing and take-off are of most use if they are immediately available to the local air traffic controller.

The ACARS is a digital HF/VHF link carrying communications both ways between an aircraft and a special network of ground stations. In the U.S.A. the network is operated by ARINC, and in the rest of the world the network is operated by SITA and is called the AIRCOM network. The extent of the ground network in Australia is shown in Fig. 4.

An aircraft at cruise altitude has a transmission range of 320-400km. The circles shown on the figure cover only a small part of Australia, but they include most of the busiest domestic

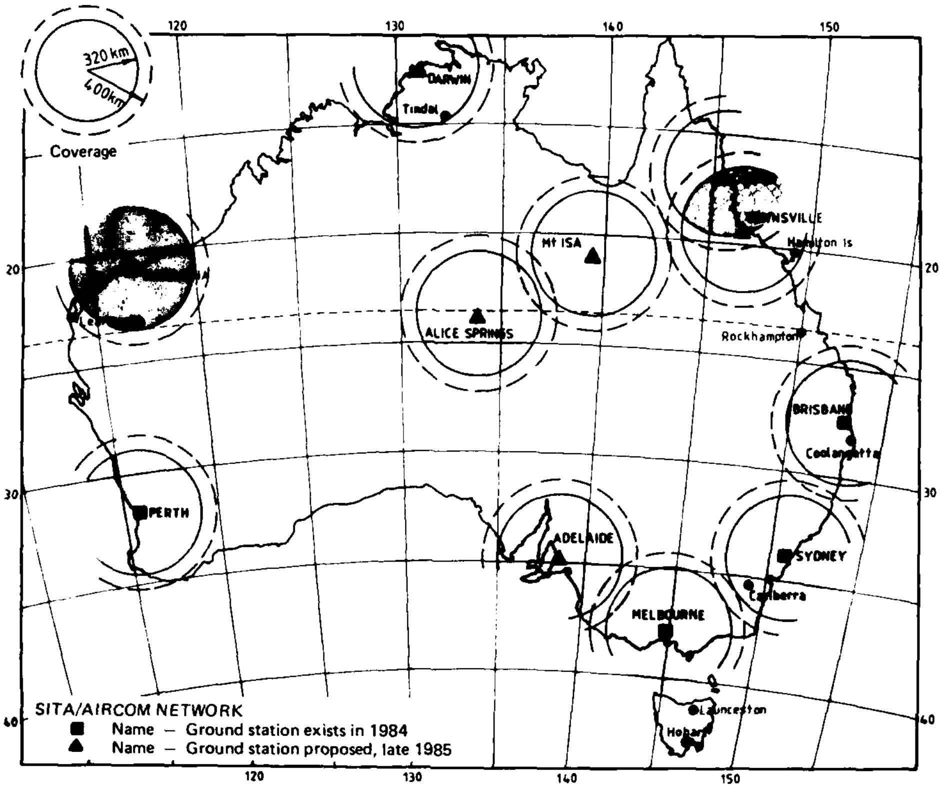

FIG. 4 COVERAGE OF AUSTRALIAN SITA/AIRCOM NETWORK

flying routes. Transmissions use a protocol in which, after the aircraft transmits a message, it waits for an acknowledgement of receipt. If no acknowledgement is received within a fixed period (about 5 or 10 seconds) the transmission is repeated. If the message is transmitted six times without acknowledgement (most probably because the aircraft is out of range of the ground network) it is stored for transmission later in the flight. A subsequent attempt to transmit the message will be made when the aircraft receives any message from the ground, or when the aircraft systems produce another automated message for transmission, or if the pilot manually initiates a transmission. In the initial ACARS units fitted to Ansett's Boeing 767's, provision is made to store up to eight meteorological messages containing 32 sets of observations. However, the normal procedure whilst the aircraft is within radio range, is to transmit a message over the ACARS network as soon as four sets of observations are available. A sample message is shown in Fig. 5. Thus on a typical take-off, with an initial climb rate of 3000 ft/min, a complete set of observations showing the low level wind shear will be transmitted within a minute of take-off. The SITA-AIRCOM network routes these messages via the Australian centre in Sydney, to the international SITA centre in Hong Kong. They are then routed back to the Ansett data processing centre and the Melbourne office of the National Forecasting Centre. The maximum normal delay in this transmission is expected to be 30 seconds. Unlike the ASDAR system a charge is made (in 1984 about 30 cents) for each message transmitted. In order to reduce costs it is planned to make use of the two way message capacity of the ACARS. When several aircraft are operating in proximity it is planned to send some of those aircraft messages which will suppress the transmission of the AMDAR data.

A1.3 The aircraft integrated data system

The AMDAR system obtains most of its data from various parts of the normal on-board avionics equipment. Because of the high cost of avionic equipment, such as the Inertial Navigation System (INS), there is a need for maximum interchangeability to minimise the cost of stocking spares. For this reason a large number of scheduled airlines have formed a corporation - Aeronautical Radio, Inc. (ARINC) - which, amongst other activities, formulates standards for electronic equipment and systems. For example, ARINC 561 is the specification for INS's.

Aircraft such as the Boeing 747, Lockheed Tristar and McDonnell Douglas DC-10 contain avionics equipment whose ARINC specifications lie in the 500 series. There is no common standard for information transfer between equipment of this type. For the most part, electrical signals into or out of this equipment consist of an analogue voltage with a reference or two analogue voltages to drive a synchro. Aircraft so equipped are frequently referred to colloquially as "analogue" aircraft.

Newer aircraft types, such as the Boeing 757 and 767 and the Airbus Industrie 300 series, are equipped with avionics designed to ARINC specifications from the 700 series. These have a common standard for digital data transmission as defined in ARINC 429 and are referred to colloquially as "digital" aircraft.

Current airworthiness regulations require that all large aircraft be fitted with a Digital Flight Data Recorder (DFDR) which records certain parameters describing the state of the aircraft. This DFDR is one of the "black box" recorders which is highly protected and used for investigations in the event of an aircraft crash. (See Aviation Safety Digest, 1980.) Data are written on a very slow speed (0.5 inch/sec, 786 bits/sec) magnetic tape loop which overwrites after about 25 hours.

The airworthiness authority prescribes mandatory parameters to be recorded on the DFDR. (The requirements are laid down in Australia by the Department of Aviation Air Navigation Orders Part 103, Section 103.19, and in the USA by FAR 121.343. See also FAR Technical Standard Order C51a, "Aircraft Flight Recorder".) The parameters prescribed in Australia are shown in Table A1.1.

The records from the DFDR are not only used in the event of a crash. They may also be used for engine monitoring, for structural fatigue life monitoring, (see e.g. de Jonge & Spiekhout, 1977, Morris and Crabill, 1980, and the talk by Finger reported in Appendix 16 of Sherman, 1982) and for investigations of wind shear incidents and statistics (see Woodfield and Woods, 1981, 1983, Woodfield, 1982). It is therefore normal for the manufacturer or operator of the aircraft to arrange for the DFDR to record additional parameters. A typical set of additional parameters is shown in Table A1.2.

A readout from the DFDR can be obtained at any time whilst the aircraft is on the ground. With some types of DFDR unit it is possible to transcribe the tape onto quarter inch reel to reel magnetic tape, whilst the recorder is still installed in the aircraft. With other types of DFDR it is necessary to exchange the entire recorder package with a spare recorder. The transcribed tape or the DFDR removed from the aircraft are then replayed at a special readout station such as the Sunstrand unit at the Department of Aviation's Air Safety Branch in Canberra. This station interfaces with a computer which can write the data on computer magnetic tape for later analysis.

A1.4 The flight data acquisition unit

The data recorded on the DFDR is obtained from various avionics units on the aircraft. The task of acquiring the data and formatting it into a data stream to feed to the DFDR is performed by the Flight Data Acquisition Unit (FDAU). This unit is basically a digital computer which monitors a large number of transducers or avionics systems and arranges their outputs into a suitable data stream. Since all the information required for the AMDAR system is available to the FDAU, it is convenient to use the FDAU also to form AMDAR messages to be transmitted

TABLE A1.1

Mandatory parameters recorded on DFDR

(*Ref:* Air Navigation Orders Part 103, Section 103.19)

Parameter	*Range*	*Min. Accuracy*	*Min. Recording Frequency*
*Time			1/min
*Altitude	−1000 ft to max	±100 ft to ±700 ft	1/sec
*Airspeed	100 knot IAS to 450 knot or V_D	±10 knots	1/sec
*Vertical acceleration	$-3g$ to $+6g$	$\pm 0.2g$	8/sec
*Heading	360°	±2°	1/sec
*Press to Xmit	On/Off		1/sec
*Pitch attitude	±75°	±2°	1/sec
*Roll attitude	±180°	±2°	1/sec
*Thrust of each engine	Full range	±2%	1/(4 sec)
*Flap position	Full range	±3%	1/(2 sec)
*Longitudinal acceleration	$\pm 1g$	$\pm 0.02g$	2/sec
*Undercarriage switch	On/Off		2/sec
*Thrust reverser (stowed/deployed) (each engine)	On/Off		1/(4 sec)
*Leading edge devices (stowed/deployed)	On/Off		1/(2 sec)
*Angle of attack	−20° to +40°	±1°	2/sec
*Lateral accel.	$\pm 1g$	$\pm 0.05g$	4/sec
*Pitch trim	Full range	±1°	1/(2 sec)
*Pitch control	Full range	±2°	1/sec
*Roll control	Full range	±2°	1/sec
*Yaw control	Full range	±2°	2/sec

over the ACARS system.** This is the procedure to be followed with the Teledyne FDAU's on the Ansett Boeing 767's.

A1.5 The Australian Implementation

A1.5.1 Reported parameters

The Boeing 767 aircraft presently in service in the Ansett fleet are being fitted with specially programmed FDAU's to transmit meteorological parameters over the ACARS radio link. The following parameters are to be included in each report:

1. INS derived wind-speed (knots).
2. INS derived wind direction (degrees true).
3. Static air temperature derived from the total air temperature sensor (degrees Celsius).
4. Aircraft roll angle flag (as required).
5. Turbulence figure in the form of derived equivalent vertical gust velocity (tenths of metre/sec).

** Or even from the special ASDAR transmitter.

TABLE A1.2

Typical Additional Parameters Recorded on DFDR

Aircraft position (latitude and longitude)
Localizer deviation
Glide slope deviation
Vertical speed
Radio altitude
Static air temperature
Exhaust gas temperature
Automatic pilot mode
Barometric setting
Command air speed setting
Marker beacons
Speed brakes
Gear status
Engine speeds
Engine pressure ratios

A1.5.2 Pressure height reference

Initially the ACARS reports will be used without any additional processing through the Bureau's on-ground computer system. The Bureau therefore decided to convert pressure readings to height on board the aircraft. The following references are used:

(a) For heights of 4000 ft or less above the aerodrome reference point, height is the value given by the (station QNH referenced) altimeter minus the aerodrome altitude read from the "look-up" table of altitudes stored in the on-board computer. Thus height is ***distance above aerodrome reference***. The look-up table is shown here as Table A1.3.

(b) Between 850 mbar and 700 mbar inclusive, height is referenced to station QNH. Thus height is ***distance above sea level.***

(c) Above 700 mbar, height is referenced to ICAO mean sea level, 1013.2 mbar.

A1.5.3 Measurement frequency

On initial climb and final descent reports will be obtained at the following heights:

$$200,\ 400,\ 600,\ 800,\ 1000,\ 1500,\ 2000,\ 3000,\ \textit{and}\ 4000\,ft$$

above the aerodrome. During the rest of the flight reports will be obtained at:

$$850,\ 780,\ 700,\ 600,\ 500,\ 400,\ 300\,mbar,$$

and at 7 minute intervals above 300 mbar. At the transition from initial climb (at 4000 ft above the aerodrome) or to final descent (at 850 mbar) the group of heights (ft or mbar) in use prior to the changeover is to be completed before the change in group is made.†

In the event that an aircraft lands at an airport whose height is not stored on-board, a zero-height altitude for the airport is assumed.

Reports will not be made precisely at the specified pressure or height, but on completion of the first set of measurements after the specified level is reached. In this connection it should be noted that the sampling frequency for monitoring aircraft altitude will be 4 samples per second. This is a faster sampling rate than that prescribed for the DFDR in Table A1.1.

† i.e. in ascent mode, the 4000 ft report will be made before the first pressure report even if the pressure at 4000 ft above the airport is less than 850 mbar. In this case, the first pressure report will be made at 780 mbar. At the end of the flight, the 850 mbar pressure report will be made prior to the changeover to the final descent mode, even if the 850 mbar height is less than 4000 ft. (In which case the first low level descent report will be made at 3000 ft.)

TABLE A1.3
AIRPORT ELEVATIONS

The table contains the names of all airports which Ansett Airlines anticipate may be used by their B767 aircraft. Also listed are the coded abbreviations for these airports as entered by the pilot, and the elevation of the respective reference points as height in feet above mean sea level.

AIRPORT	*ABBREVIATION*	*ELEVATION*
Adelaide	ADL	20
Alice Springs	ASP	1789
Brisbane	BNE	18
Cairns	CNS	10
Canberra	CBR	1888
Coolangatta	OOL	21
Darwin	DRW	102
Hamilton Island	HTI	30
Hobart	HBA	13
Learmonth	LEA	19
Launceston	LST	562
Melbourne	MEL	434
Mt Isa	ISA	1121
Perth	PER	67
Rockhampton	ROK	34
Sydney	SYD	21
Tindal	KTR	443
Townsville	TSV	18

A1.5.4 Roll angle flag

Aircraft roll angle will be continuously monitored and a flag character "R" will be inserted in the report immediately following wind speed if the roll angle is greater than 3 degrees at any time during the wind measurement period for that report. It is considered that the INS derived winds may be significantly in error if such roll angles occur during their measurement.

A1.5.5 Turbulence

The turbulence parameter is derived equivalent gust velocity in tenths of a metre/second. The calculation is according to the formula:

$$U_{de} = 10 \times \frac{A \cdot m \cdot \Delta n}{V_c} \qquad (A1.1)$$

where

* Δn is the modulus of the peak deviation of the aircraft vertical acceleration from 1g in units of g,
* m is the total aircraft mass in metric tonnes,
* V_c is the calibrated air speed at the time of occurrence of the acceleration peak in knots,
* A is given by the formula:

$$A = 12 + \frac{800}{50 + H} \qquad (A1.2)$$

which differs slightly from equation 3.1, being based on earlier preliminary calculations (which did not distinguish between calibrated air speed and equivalent air speed).
* H is the altitude in thousands of feet.

The quantity of on-board computation will be reduced if equations A1.1 and A1.2 are not evaluated in full each time a new vertical acceleration value is sampled. The values of m and H (and hence of A) will, in general, change only slowly, so it is sufficient to determine them only

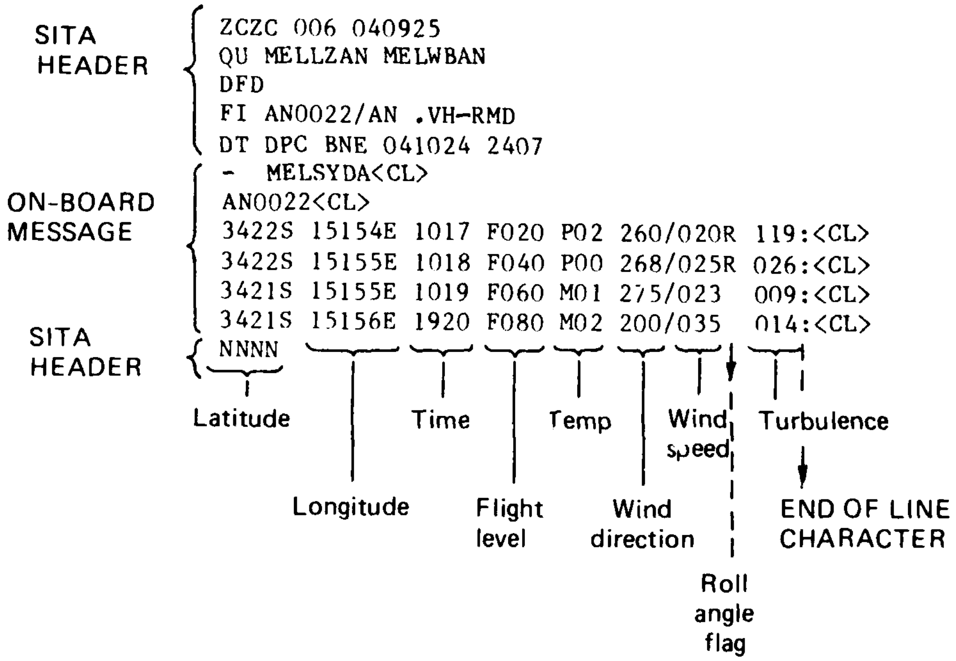

FIG. 5 PROPOSED ACARS MESSAGE FORMAT

once during each turbulence reporting period of 7 minutes or less. The value of V_c may change considerably during a seven minute reporting period, so it is important that the values of aircraft vertical acceleration and calibrated air speed be nearly contemporaneous. In general it will be satisfactory if the maximum acceleration deviation during each 5 second period is divided by the contemporaneous value of the air speed. Then the maximum value of this quotient during a reporting period is used in equation A1.2.

A1.5.6 Message format

A typical message is shown in Fig. 5, where the two header sections are provided by SITA (as per the Ansett sample).

The meteorological text commences with an identifier (7 characters) which consists of three parts, departure port (3 characters), destination port (3 characters) and data type (1 character: A - ascending profile, D - descending profile, C - cruise level data). The identifier is followed on the next line by the aircraft flight number.

Times are given as Greenwich Mean Time (GMT)‡, flight level is the altitude in units of 100 ft, temperatures are in degrees Celsius with sign indicated by a letter (P - plus, M - minus), wind direction is in degrees true, wind speed in knots, R is used to denote roll angles greater than 3 degrees and the turbulence indicator is the derived equivalent gust velocity in tenths of a metre/sec.

A special end-of-report character (colon) is used to separate individual reports within the message and the symbol "<CL>" at the end of a line denotes a carriage return and a line feed character.

‡ or Universal Co-ordinated Time (UCT)

APPENDIX 2

RELATIONS BETWEEN AIR SPEEDS, MACH NUMBER AND STAGNATION TEMPERATURE

The following derivations are taken with little modification from Dommasch et al(1958).

A2.1 Incompressible flow

At low speeds the airflow round an aircraft can be considered incompressible. The pitot tube measures the dynamic pressure, q, corresponding to the aircraft's speed, V.

$$q = \frac{1}{2}\rho V^2 \tag{A2.1}$$

The air density, ρ, is a function of altitude. The air speed indicators of some low-speed commercial aeroplanes are calibrated in accordance with this equation, using for ρ the value ρ_0 corresponding to sea level. The indicator is said to read the "Equivalent Air Speed", (EAS), V_e, where

$$V_e = \sqrt{2q/\rho_0} \tag{A2.2}$$

In general the True Air Speed (TAS), V or V_t differs from the equivalent air speed.

$$V_t = V_e \times \sqrt{\frac{\rho_0}{\rho}} \tag{A2.3}$$

$$= \frac{V_e}{\sqrt{\sigma}} \tag{A2.4}$$

A2.2 Compressible flow

The total energy of a unit mass is made up of:

* internal energy, u, which is a function of temperature, T,
* mechanical potential energy, pv, where p is the pressure and v is the specific volume,
* potential energy, gz, due to altitude, z,
* kinetic energy, $\frac{1}{2}V^2$.

For constant energy flow,

$$u + pv + gz + \frac{V^2}{2} = Constant \tag{A2.5}$$

For flow around an aircraft the height z does not change appreciably, and the term gz may be ignored. The internal energy, u, is defined as

$$u = c_v \times T \tag{A2.6}$$

and because of the equation of state

$$pv = RT \tag{A2.7}$$

we have

$$u = pv\frac{c_v}{R} \tag{A2.8}$$

The sum $u + pv$ is termed the enthalpy, h, and because of the two relations

$$R = c_p - c_v \tag{A2.9}$$

$$\gamma = \frac{c_p}{c_v} \tag{A2.10}$$

we have the following alternative expressions for the enthalpy

$$h = pv\left(\frac{c_v}{R} + 1\right) \qquad (A2.11)$$

$$= \frac{p}{\rho} \times \frac{\gamma}{\gamma - 1} \qquad (A2.12)$$

$$= RT \times \frac{\gamma}{\gamma - 1} \qquad (A2.13)$$

$$= \frac{V_a^2}{\gamma - 1} \qquad (A2.14)$$

where the speed of sound, V_a, is given by

$$V_a^2 = \gamma RT = \frac{\gamma p}{\rho} \qquad (A2.15)$$

When the airflow is brought to rest (relative to the aircraft) at a stagnation point, such as the front of the pitot head or the stagnation temperature probe, the pressure, density, temperature and enthalpy take on new values denoted by the subscript "t", and V becomes zero. Thus equation A2.5 may be re-written as

$$h + \frac{V^2}{2} = h_t \qquad (A2.16)$$

Using A2.13 we obtain

$$\frac{\gamma}{\gamma - 1} \times RT + \frac{V^2}{2} = \frac{\gamma}{\gamma - 1} \times RT_t \qquad (A2.17)$$

so that the relationship between measured stagnation temperature, T_t and the free stream temperature, T, is given by

$$\frac{T_t}{T} = 1 + \frac{\gamma - 1}{2} \times M^2 \qquad (A2.18)$$

This gives the Mach number $M = \frac{V}{V_a}$ as

$$M^2 = \frac{2}{\gamma - 1} \times \left(\frac{T_t}{T} - 1\right) \qquad (A2.19)$$

which, for isentropic flow to stagnation (this implies that the Mach number is less than unity) gives

$$M^2 = \frac{2}{\gamma - 1} \times \left[\left(\frac{p_t}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad (A2.20)$$

$$= \frac{2}{\gamma - 1} \times \left[\left(\frac{p_t - p}{p} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad (A2.21)$$

Equation A2.21 is the calibration equation for Mach meters at subsonic speeds. Mach meters measure the ratio of the two quantities $(p_t - p)$ and p. From equation A2.21 we may also derive

$$V^2 = \frac{2V_a^2}{\gamma - 1} \times \left[\left(\frac{p_t - p}{p} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad (A2.22)$$

Airspeed indicators use a calibration based on equation A2.22, but since they only measure the pressure difference, $(p_t - p)$, they assume V_a to have its sea level value, V_{a0}, and p in the denominator term, to have its sea level value, p_0. The resultant airspeed is called the "Calibrated Air Speed" (CAS), V_c.

$$V_c^2 = \frac{2V_{a0}^2}{\gamma - 1} \times \left[\left(\frac{p_t - p}{p_0} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \qquad (A2.23)$$

There is a small difference between equivalent airspeed and calibrated airspeed. From equations A2.3 and A2.22 we have

$$V_e^2 = V^2\left(\frac{\rho}{\rho_0}\right)$$

$$= \frac{2\gamma p}{(\gamma-1)\rho_0} \times \left[\left(\frac{p_t - p}{p} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \tag{A2.24}$$

and from equations A2.15 and A2.23

$$V_c^2 = \frac{2\gamma p_0}{(\gamma-1)\rho_0} \times \left[\left(\frac{p_t - p}{p_0} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \tag{A2.25}$$

$$\left(\frac{V_c}{V_e}\right)^2 = \frac{p_0}{p} \times \frac{\left[\left(\frac{p_t-p}{p_0} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{\left[\left(\frac{p_t-p}{p} + 1\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \tag{A2.26}$$

An empirical formula for the ratio of these two velocities which applies very closely, at least in the range $0 \leq H \leq 45$ and $0 \leq M \leq 0.95$ is

$$\frac{V_c}{V_e} = 1 + \frac{H(140 - H)}{4000} \times \frac{M^2}{10} \tag{A2.27}$$

where H is the altitude in thousands of feet.

APPENDIX 3

CALCULATIONS FOR BOEING 767

A3.1 Flight profile information for typical Australian route

A3.1.1 Velocity (CAS)

Take-off	150 knots
at 1500 ft	200 knots
at 3000 ft	300 knots
	Maintain 300 knots until Mach 0.8 attained
	Maintain Mach 0.8 for rest of climb, cruise, and start of descent
	Maintain 300 knots down to 5000 ft
at 5000 ft	300 knots
at 3000 ft	210 knots
Land at	140 knots

A3.1.2 Altitude

Cruise altitude is around 40 000 ft, with estimated probability distribution as follows:

Cruise Altitude (ft)	Per-cent of Cruise Time at altitude
L.T. 35000	5
35000	10
37000	20
39000	30
41000	25
43000	10

The aircraft climbs to cruise altitude in about 20 minutes, with an initial rate of climb of 3000 ft/min, reducing, late in the climb, to 1000 ft/min. The aircraft descends in approximately 25 minutes with an initial rate of descent of 4000 ft/min, reducing to 2000 ft/min at 5000 ft and zero at ground level. (The last ten miles of flight occur over the last 3000 ft of altitude.)

A3.1.3 Weight

Empty	80 Tonne
Max Take-off	140 Tonne
Average at brake release	110 Tonne
Average at cruise	107 Tonne
Average at landing	105 Tonne

A3.2 Calculations

In the tables following, those columns headed U.S. are computed using the American formula for the gust alleviation factor (see equation 2.6) and those headed U.K. are based on the ESDU data item 69023 applied to the Boeing 767.

* Table A3.1 gives calculated values of A for the typical altitude-speed combinations shown. The values of A for different aircraft weights are shown in the separate sections of the table and graphed in Fig 1.
* Table A3.2 shows calculated values of A for the light weight condition and flight at various heights and various constant Mach numbers. (Mach numbers between 0.71 and 0.83 all give the same values for A.)
* Tables A3.3 and A3.4 are similar to Table A3.2, except that they are based respectively on the mean and heavy weight conditions of the aircraft. The results of Table A3.3 are graphed in Fig. 2.
* Table A3.5 shows a typical whole flight profile and for this profile Table A3.6 shows the expected numbers of exceedances of various U_{de} values per 1000 hours of flying.

TABLE A3.1

Variation of A with weight for typical flight profile

#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1500	200	.31	1.172	5.44	80	12.0	.61	.66	12.89	11.84	29.6	29.4
2	4000	300	.49	1.088	5.71	80	12.3	.61	.65	8.15	7.65	28.7	28.7
3	7500	300	.52	.978	5.78	80	13.5	.63	.67	7.86	7.44	27.9	27.9
4	12500	300	.57	.836	5.90	80	15.5	.66	.68	7.47	7.15	26.8	27.0
5	17500	300	.62	.710	6.05	80	17.8	.68	.70	7.11	6.88	25.8	26.1
6	22500	300	.68	.599	6.19	80	20.6	.70	.71	6.80	6.66	25.0	25.3
7	27500	300	.75	.502	6.31	80	24.0	.72	.73	6.54	6.49	24.3	24.5
8	32500	288	.80	.418	6.39	80	28.6	.74	.74	6.61	6.63	23.9	23.9
9	37500	256	.80	.340	6.38	80	35.1	.76	.76	7.26	7.27	23.3	23.3
10	42500	229	.80	.267	6.39	80	44.6	.79	.79	7.92	7.93	22.7	22.8
#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1500	200	.31	1.172	5.44	110	16.4	.67	.72	16.24	15.07	27.4	27.0
2	4000	300	.49	1.088	5.71	110	16.9	.67	.71	10.28	9.75	26.6	26.4
3	7500	300	.52	.978	5.78	110	18.5	.68	.72	9.98	9.52	26.0	25.9
4	12500	300	.57	.836	5.90	110	21.3	.70	.73	9.56	9.20	25.1	25.2
5	17500	300	.62	.710	6.05	110	24.4	.72	.74	9.16	8.89	24.3	24.6
6	22500	300	.68	.599	6.19	110	28.3	.74	.76	8.82	8.66	23.6	23.9
7	27500	300	.75	.502	6.31	110	33.1	.76	.76	8.55	8.49	23.2	23.3
8	32500	288	.80	.418	6.39	110	39.3	.78	.77	8.71	8.72	22.8	23.0
9	37500	256	.80	.340	6.38	110	48.3	.79	.79	9.63	9.63	22.4	22.5
10	42500	229	.80	.267	6.39	110	61.4	.81	.81	10.57	10.57	22.0	22.1
#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1500	200	.31	1.172	5.44	140	20.9	.70	.75	19.59	18.24	26.1	25.7
2	4000	300	.49	1.088	5.71	140	21.5	.71	.74	12.42	11.81	25.3	25.2
3	7500	300	.52	.978	5.78	140	23.6	.72	.75	12.10	11.56	24.8	24.7
4	12500	300	.57	.836	5.90	140	27.1	.74	.76	11.65	11.22	24.0	24.2
5	17500	300	.62	.710	6.05	140	31.1	.75	.77	11.21	10.89	23.3	23.6
6	22500	300	.68	.599	6.19	140	36.0	.77	.78	10.85	10.64	22.8	23.1
7	27500	300	.75	.502	6.31	140	42.1	.78	.79	10.56	10.48	22.5	22.6
8	32500	288	.80	.418	6.39	140	50.0	.80	.80	10.80	10.80	22.2	22.3
9	37500	256	.80	.340	6.38	140	61.5	.81	.81	11.99	11.98	21.9	22.0
10	42500	229	.80	.267	6.39	140	78.1	.82	.83	13.23	13.21	21.6	21.6

TABLE A3.2

Variation of A with Mach number for light weight case

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	521	.80	1.190	6.38	80	10.0	.58	.59	4.47	4.37	28.5	28.7
2	5000	488	.80	1.056	6.38	80	11.3	.60	.61	4.63	4.56	27.8	28.0
3	10000	449	.80	.905	6.38	80	13.2	.63	.63	4.85	4.81	27.0	27.1
4	15000	410	.80	.771	6.38	80	15.5	.66	.66	5.14	5.11	26.2	26.3
5	20000	374	.80	.653	6.39	80	18.3	.68	.68	5.46	5.45	25.5	25.6
6	25000	338	.80	.549	6.38	80	21.7	.71	.71	5.86	5.87	24.8	24.9
7	30000	305	.80	.458	6.39	80	26.0	.73	.73	6.32	6.34	24.2	24.3
8	35000	273	.80	.380	6.39	80	31.4	.75	.75	6.90	6.91	23.6	23.6
9	40000	243	.80	.302	6.39	80	39.6	.78	.77	7.55	7.56	23.0	23.0
10	45000	216	.80	.237	6.39	80	50.3	.80	.80	8.31	8.31	22.4	22.5

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	390	.60	1.190	5.99	80	10.7	.59	.62	6.22	5.90	28.8	29.0
2	5000	364	.60	1.056	5.99	80	12.0	.61	.64	6.45	6.16	28.0	28.2
3	10000	333	.60	.905	5.99	80	14.1	.64	.67	6.79	6.51	27.1	27.4
4	15000	304	.60	.771	6.00	80	16.5	.67	.69	7.17	6.91	26.2	26.5
5	20000	276	.60	.653	6.00	80	19.5	.69	.72	7.64	7.38	25.4	25.8
6	25000	249	.60	.549	6.00	80	23.1	.72	.74	8.21	7.94	24.7	25.1
7	30000	224	.60	.458	6.00	80	27.7	.74	.76	8.87	8.59	24.1	24.4
8	35000	200	.60	.380	6.00	80	33.4	.76	.78	9.69	9.38	23.5	23.8
9	40000	178	.60	.302	6.00	80	42.1	.78	.81	10.61	10.27	22.8	23.2
10	45000	158	.60	.237	6.00	80	53.5	.80	.83	11.69	11.30	22.3	22.6

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	325	.50	1.190	5.74	80	11.2	.60	.64	7.69	7.20	29.3	29.3
2	5000	303	.50	1.056	5.74	80	12.6	.62	.66	7.97	7.51	28.4	28.4
3	10000	277	.50	.905	5.74	80	14.7	.65	.68	8.39	7.94	27.5	27.5
4	15000	252	.50	.771	5.74	80	17.2	.67	.71	8.89	8.45	26.6	26.7
5	20000	228	.50	.653	5.74	80	20.3	.70	.73	9.50	9.05	25.8	25.9
6	25000	206	.50	.549	5.74	80	24.2	.72	.76	10.20	9.73	25.1	25.2
7	30000	184	.50	.458	5.74	80	29.0	.74	.78	11.11	10.60	24.4	24.6
8	35000	165	.50	.380	5.74	80	34.9	.76	.80	12.08	11.53	23.8	23.9
9	40000	146	.50	.302	5.74	80	44.0	.79	.82	13.30	12.68	23.1	23.3
10	45000	130	.50	.237	5.74	80	56.0	.80	.84	14.62	13.93	22.6	22.7

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	195	.30	1.190	5.43	80	11.8	.61	.66	13.30	12.20	29.7	29.5
2	5000	182	.30	1.056	5.43	80	13.3	.63	.68	13.77	12.69	28.9	28.6
3	10000	165	.30	.905	5.43	80	15.5	.66	.71	14.61	13.52	27.9	27.7
4	15000	150	.30	.771	5.43	80	18.2	.68	.73	15.48	14.37	26.9	26.8
5	20000	135	.30	.653	5.43	80	21.5	.71	.76	16.62	15.46	26.1	26.1
6	25000	122	.30	.549	5.43	80	25.6	.73	.78	17.83	16.61	25.3	25.3
7	30000	109	.30	.458	5.43	80	30.6	.75	.81	19.41	18.08	24.6	24.7
8	35000	97	.30	.380	5.43	80	37.0	.77	.83	21.29	19.82	24.0	24.0
9	40000	86	.30	.302	5.43	80	46.6	.79	.85	23.38	21.75	23.4	23.4
10	45000	77	.30	.237	5.43	80	59.2	.81	.87	25.58	23.78	22.9	22.8

TABLE A3.3

Variation of A with Mach number for medium weight case

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	521	.80	1.190	6.38	110	13.8	.64	.64	5.57	5.53	26.2	26.3
2	5000	488	.80	1.056	6.38	110	15.6	.66	.66	5.81	5.79	25.7	25.8
3	10000	449	.80	.905	6.38	110	18.1	.68	.68	6.15	6.14	25.1	25.2
4	15000	410	.80	.771	6.38	110	21.3	.70	.70	6.57	6.57	24.5	24.7
5	20000	374	.80	.653	6.39	110	25.1	.73	.73	7.04	7.05	24.0	24.2
6	25000	338	.80	.549	6.38	110	29.9	.75	.75	7.63	7.64	23.5	23.7
7	30000	305	.80	.458	6.39	110	35.8	.77	.76	8.30	8.31	23.0	23.2
8	35000	273	.80	.380	6.39	110	43.2	.78	.78	9.11	9.12	22.6	22.7
9	40000	243	.80	.302	6.39	110	54.4	.80	.80	10.05	10.05	22.2	22.3
10	45000	216	.80	.237	6.39	110	69.2	.82	.82	11.13	11.12	21.8	21.9
#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	390	.60	1.190	5.99	110	14.7	.65	.67	7.78	7.47	26.5	26.7
2	5000	364	.60	1.056	5.99	110	16.6	.67	.69	8.13	7.83	25.9	26.1
3	10000	333	.60	.905	5.99	110	19.3	.69	.72	8.64	8.34	25.2	25.5
4	15000	304	.60	.771	6.00	110	22.7	.71	.74	9.20	8.90	24.6	24.9
5	20000	276	.60	.653	6.00	110	26.8	.73	.76	9.89	9.57	24.0	24.3
6	25000	249	.60	.549	6.00	110	31.8	.75	.78	10.71	10.37	23.5	23.8
7	30000	224	.60	.458	6.00	110	38.1	.77	.80	11.67	11.29	23.0	23.4
8	35000	200	.60	.380	6.00	110	46.0	.79	.82	12.82	12.40	22.6	22.9
9	40000	178	.60	.302	6.00	110	57.9	.81	.83	14.14	13.67	22.1	22.4
10	45000	158	.60	.237	6.00	110	73.6	.82	.85	15.68	15.13	21.7	22.0
#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	325	.50	1.190	5.74	110	15.3	.65	.69	9.64	9.14	27.0	26.9
2	5000	303	.50	1.056	5.74	110	17.3	.67	.71	10.08	9.58	26.4	26.3
3	10000	277	.50	.905	5.74	110	20.2	.70	.73	10.70	10.19	25.7	25.6
4	15000	252	.50	.771	5.74	110	23.7	.72	.75	11.44	10.91	25.0	25.0
5	20000	228	.50	.653	5.74	110	28.0	.74	.78	12.33	11.76	24.4	24.5
6	25000	206	.50	.549	5.74	110	33.2	.76	.80	13.34	12.73	23.8	24.0
7	30000	184	.50	.458	5.74	110	39.8	.78	.81	14.64	13.96	23.3	23.5
8	35000	165	.50	.380	5.74	110	48.1	.79	.83	16.02	15.27	22.9	23.0
9	40000	146	.50	.302	5.74	110	60.5	.81	.85	17.75	16.90	22.4	22.6
10	45000	130	.50	.237	5.74	110	76.9	.82	.87	19.63	18.66	22.1	22.1
#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.	A	EQUN. (3.5)
1	1000	195	.30	1.190	5.43	110	16.2	.66	.72	16.74	15.51	27.5	27.1
2	5000	182	.30	1.056	5.43	110	18.3	.68	.73	17.46	16.22	26.8	26.5
3	10000	165	.30	.905	5.43	110	21.4	.70	.76	18.69	17.38	26.1	25.8
4	15000	150	.30	.771	5.43	110	25.1	.73	.78	19.98	18.60	25.4	25.2
5	20000	135	.30	.653	5.43	110	29.6	.75	.80	21.62	20.14	24.7	24.6
6	25000	122	.30	.549	5.43	110	35.2	.76	.82	23.37	21.77	24.1	24.1
7	30000	109	.30	.458	5.43	110	42.1	.78	.84	25.62	23.84	23.6	23.6
8	35000	97	.30	.380	5.43	110	50.9	.80	.86	28.27	26.29	23.2	23.1
9	40000	86	.30	.302	5.43	110	64.0	.81	.88	31.25	29.02	22.7	22.7
10	45000	77	.30	.237	5.43	110	81.4	.83	.89	34.39	31.91	22.3	22.3

TABLE A3.4

Variation of A with Mach number for heavy weight condition

#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1000	521	.80	1.190	6.38	140	17.6	.68	.68	6.67	6.65	24.8	24.9
2	5000	488	.80	1.056	6.38	140	19.8	.69	.69	7.00	6.99	24.4	24.5
3	10000	449	.80	.905	6.38	140	23.1	.72	.71	7.45	7.46	23.9	24.1
4	15000	410	.80	.771	6.38	140	27.1	.74	.73	8.01	8.02	23.5	23.7
5	20000	374	.80	.653	6.39	140	32.0	.75	.75	8.63	8.65	23.1	23.3
6	25000	338	.80	.549	6.38	140	38.1	.77	.77	9.40	9.41	22.7	22.9
7	30000	305	.80	.458	6.39	140	45.6	.79	.79	10.27	10.28	22.4	22.5
8	35000	273	.80	.380	6.39	140	55.0	.80	.80	11.33	11.33	22.1	22.2
9	40000	243	.80	.302	6.39	140	69.2	.82	.82	12.54	12.53	21.8	21.8
10	45000	216	.80	.237	6.39	140	88.1	.83	.83	13.95	13.91	21.5	21.5
#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1000	390	.60	1.190	5.99	140	18.7	.69	.71	9.34	9.02	25.1	25.3
2	5000	364	.60	1.056	5.99	140	21.1	.70	.73	9.81	9.49	24.7	24.8
3	10000	333	.60	.905	5.99	140	24.6	.72	.75	10.49	10.15	24.1	24.3
4	15000	304	.60	.771	6.00	140	28.9	.74	.77	11.24	10.88	23.6	23.9
5	20000	276	.60	.653	6.00	140	34.1	.76	.79	12.14	11.75	23.2	23.5
6	25000	249	.60	.549	6.00	140	40.5	.78	.80	13.22	12.79	22.7	23.1
7	30000	224	.60	.458	6.00	140	48.5	.79	.82	14.46	13.98	22.4	22.7
8	35000	200	.60	.380	6.00	140	58.5	.81	.84	15.96	15.42	22.0	22.3
9	40000	178	.60	.302	6.00	140	73.7	.82	.85	17.68	17.06	21.7	22.0
10	45000	158	.60	.237	6.00	140	93.7	.83	.86	19.67	18.96	21.4	21.6
#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1000	325	.50	1.190	5.74	140	19.5	.69	.73	11.59	11.04	25.6	25.5
2	5000	303	.50	1.056	5.74	140	22.0	.71	.74	12.18	11.61	25.1	25.0
3	10000	277	.50	.905	5.74	140	25.7	.73	.76	13.01	12.41	24.6	24.5
4	15000	252	.50	.771	5.74	140	30.1	.75	.78	13.99	13.35	24.0	24.1
5	20000	228	.50	.653	5.74	140	35.6	.77	.80	15.16	14.46	23.5	23.6
6	25000	206	.50	.549	5.74	140	42.3	.78	.82	16.48	15.72	23.1	23.2
7	30000	184	.50	.458	5.74	140	50.7	.80	.84	18.16	17.30	22.7	22.8
8	35000	165	.50	.380	5.74	140	61.2	.81	.85	19.95	19.00	22.4	22.5
9	40000	146	.50	.302	5.74	140	77.0	.82	.87	22.20	21.11	22.0	22.1
10	45000	130	.50	.237	5.74	140	97.9	.83	.88	24.64	23.40	21.7	21.8
#	HEIGHT	CAS	MACH	DENSITY	DCLDA	MASS	MU	ALLEVIATN		UDE(M/S/G)		A	EQUN.
	FT	KTS		KG/CU.M	/RAD	TONNE		U.S.	U.K.	U.S.	U.K.		(3.5)
1	1000	195	.30	1.190	5.43	140	20.7	.70	.75	20.18	18.77	26.1	25.8
2	5000	182	.30	1.056	5.43	140	23.3	.72	.77	21.16	19.70	25.6	25.2
3	10000	165	.30	.905	5.43	140	27.2	.74	.79	22.77	21.21	25.0	24.7
4	15000	150	.30	.771	5.43	140	31.9	.75	.81	24.47	22.79	24.4	24.2
5	20000	135	.30	.653	5.43	140	37.7	.77	.83	26.62	24.79	23.9	23.8
6	25000	122	.30	.549	5.43	140	44.8	.79	.85	28.91	26.90	23.4	23.4
7	30000	109	.30	.458	5.43	140	53.6	.80	.86	31.83	29.59	23.0	23.0
8	35000	97	.30	.380	5.43	140	64.8	.81	.88	35.26	32.74	22.7	22.6
9	40000	86	.30	.302	5.43	140	81.5	.83	.89	39.12	36.28	22.3	22.2
10	45000	77	.30	.237	5.43	140	103.6	.84	.90	43.20	40.03	22.0	21.9

TABLE A3.5

Typical flight profile

#	HEIGHT FT	CAS KTS	MACH	DENSITY KG/CU.M	DCLDA /RAD	MASS TONNE	TIME MIN	MU	ALLEVIATN U.S.	ALLEVIATN U.K.	UDE(M/S/G) U.S.	UDE(M/S/G) U.K.
						— CLIMB —						
* 1	1500	200	0.31	1.172	5.44	110	2	16.4	0.67	0.72	16.24	15.07
* 2	4000	300	0.49	1.088	5.71	110	1	16.9	0.67	0.71	10.28	9.75
* 3	7500	300	0.52	0.978	5.78	110	2	18.5	0.68	0.72	9.98	9.52
* 4	12500	300	0.57	0.836	5.90	110	2	21.3	0.70	0.73	9.56	9.20
* 5	17500	300	0.62	0.710	6.05	110	2	24.4	0.72	0.74	9.16	8.89
* 6	22500	300	0.68	0.599	6.19	110	2	28.3	0.74	0.76	8.82	8.66
* 7	27500	300	0.75	0.502	6.31	110	3	33.1	0.76	0.76	8.55	8.49
* 8	32500	288	0.80	0.418	6.39	110	3	39.3	0.78	0.77	8.71	8.72
* 9	37500	256	0.80	0.340	6.38	110	3	48.3	0.79	0.79	9.63	9.63
						— CRUISE —						
*10	37500	256	0.80	0.340	6.38	107	20	47.0	0.79	0.79	9.39	9.39
*11	42500	229	0.80	0.267	6.39	107	6	59.7	0.81	0.81	10.31	10.30
						— DESCENT —						
*12	37500	256	0.80	0.340	6.38	105	2	46.1	0.79	0.79	9.23	9.24
*13	32500	288	0.80	0.418	6.39	105	2	37.5	0.77	0.77	8.36	8.37
*14	27500	300	0.75	0.502	6.31	105	2	31.6	0.75	0.76	8.22	8.16
*15	22500	300	0.68	0.599	6.19	105	2	27.0	0.74	0.75	8.49	8.32
*16	17500	300	0.62	0.710	6.05	105	3	23.3	0.72	0.74	8.82	8.56
*17	12500	300	0.57	0.836	5.90	105	3	20.3	0.70	0.73	9.21	8.86
*18	7500	300	0.52	0.978	5.78	105	3	17.7	0.68	0.71	9.63	9.17
*19	4000	250	0.41	1.088	5.57	105	2	16.5	0.67	0.71	12.13	11.38
*20	1500	175	0.27	1.172	5.40	105	1	15.8	0.66	0.71	18.02	16.64

TABLE A3.6

Expected numbers of exceedances per 1000 hours of flying according to flight profile given in Table A3.5

Ude (m/s)	Exceedances per 1000 Hours: Upgusts	Downgusts	Total
1.5	28,100	16,600	44,700
3.0	4,270	2,370	6,640
4.5	576	325	901
6.0	102	58	160
7.5	21	12	33
9.0	6	3	9

APPENDIX 4

RESULTS FOR OTHER AIRCRAFT TYPES: COMPUTATION OF LIFT CURVE SLOPE

Lift curve slopes have been estimated using the USAF Stability and Control DATCOM (Finck, 1975). In applying this reference, the lift on the fuselage has been accounted for by considering an enlarged wing and tail. The wing and tail are considered to be extrapolated right through the fuselage by continuation of inboard leading and trailing edges to the aircraft centreline. The lift curve slope for the entire aircraft is computed as

$$a = a_w + a_t \times \frac{\text{Tail Area}}{\text{Wing Area}} \qquad (A4.1)$$

where a_w and a_t denote the lift curve slopes of the enlarged wing and tail respectively.

Below a Mach number of about 0.6 the lift curve slope varies parabolically with Mach number.

$$a = b_1 + b_2 M^2 \qquad (A4.2)$$

At higher Mach numbers the approach to the force break Mach number complicates this formula. Up to the force break Mach number, the following formula has been found to fit the data reasonably well. (i.e. lift curve slope predicted generally within 1%.)

$$a = (b_1 + b_2 M^2) \times \left\{ 1 - b_4 + b_4 \left[1 - b_5 \left(\frac{M}{b_3} \right)^{16} - (1 - b_5) \left(\frac{M}{b_3} \right)^{64} \right]^2 \right\} \qquad (A4.3)$$

Values of the parameters $b_1, \ldots, b_5$ are given in the following table.

Aircraft Type	S m^2	c m	b_1	b_2	b_3	b_4	b_5
A300-B4	258.8	6.6	5.32	2.40	0.88	0.6	−0.23
A310	225.6	6.2	5.51	2.40	0.89	0.6	−0.05
A320-200	125.4	4.3	5.55	2.64	0.88	0.6	0
B727	158	5.5	4.89	1.76	0.90	0.6	−0.05
B737-300	103.4	4.3	5.58	2.53	0.90	0.6	+0.15
B747-200B	550	10.6	4.73	1.60	0.92	0.6	−0.1
B747SP	550	10.6	4.84	1.54	0.92	0.6	−0.25
B767	291	7.2	5.24	2.00	0.90	0.6	+0.10
DC10-30	385	9.0	5.31	2.00	0.91	0.6	−0.20
L1011-500	349	8.3	5.33	2.10	0.90	0.6	−0.20

APPENDIX 5

LIST OF RELEVANT ARINC SPECIFICATIONS

Number	*Subject*
419	Digital Data System Compendium
429-5	Mark 33 Digital Information Transfer System (DITS)
545	Subsonic Air Data Computer System
561-11	Inertial Navigation System (INS)
563-1	Aircraft Integrated Data System (AIDS)
565	Mark-2 Subsonic Air Data System
571-2	Inertial Sensor System(ISS)
573-7	Mark-2 Aircraft Integrated Data System (AIDS Mark-2)
575-3	Mark-3 Sub-sonic Air Data System (Digital) (DADS)
597-1	ARINC Communications Addressing and Reporting System
599	Mark-2 Omega Navigation System
704-1	Inertial Reference System
706-1	Mark-5 Sub-sonic Air Data System
724	Mark-2 ARINC Communications Addressing & Reporting System

APPENDIX 6

ACRONYMS AND ABBREVIATIONS

AAU	- *ASDAR Avionics Unit*
ACARS	- *ARINC Communications Addressing and Reporting System*
ADC	- *Air Data Computer*
AIDS	- *Aircraft Integrated Data System*
AIRCOM	- *Air Communications*
AMDAR	- *Aircraft Meteorological Data Relay*
ARINC	- *Aeronautical Radio Inc.*
ASDAR	- *Aircraft to Satellite Data Relay*
BS	- *Body Station (Distance aft of a reference location on an aircraft)*
CAA	- *Civil Aviation Authority (U.K.)*
CAD	- *Consortium for ASDAR Development*
CADC	- *Central Air Data Computer*
CAS	- *Calibrated Air Speed*
CGMS	- *Co-ordination, Geostationary Meteorological Satellites*
DADS	- *Digital Air Data System*
DCP	- *Data Collection Platform*
DFDR	- *Digital Flight Data Recorder*
DITS	- *Digital Information Transfer System*
EAS	- *Equivalent Air Speed*
EGT	- *Exhaust Gas Temperature*
ESDU	- *Engineering Sciences Data Unit*
FAA	- *Federal Aviation Authority (U.S.)*
FAR	- *Federal Aviation Regulations*
FDAU	- *Flight Data Acquisition Unit*
FGGE	- *First GARP Global Experiment*
GARP	- *Global Atmospheric Research Program*
GMS	- *Geosynchronous Meteorological Satellite*
GMT	- *Greenwich Mean Time*
GTS	- *Global Telecommunications System (of WMO)*
ICAO	- *International Civil Aviation Organisation*
INS	- *Inertial Navigation System*
ISS	- *Inertial Sensor System*
JAR	- *Joint Aviation Regulations*
NESDIS	- *National Environmental Satellite Data and Information Service (Agency of NOAA)*
NOAA	- *National Oceanic and Atmospheric Administration (U.S.)*
PIREP	- *Pilot Report*
QNH	- *This is the symbol, in the international Q code, for the estimated mean sea level pressure at a particular place and time. An aircraft altimeter, with its pressure reference set to local QNH, will read the actual aerodrome altitude when the aircraft is at rest on the ground.*
SITA	- *Societe Internationale de Telecommunications Aeronautiques*
TAS	- *True Air Speed*
TAT	- *Total Air Temperature*
UDE	- *Derived Equivalent Gust Velocity*
WMO	- *World Meteorological Organisation*
WWW	- *World Weather Watch*

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16. Abstract

AMDAR is a system of measuring wind speed, wind direction, air temperature and an indication of turbulence from INS-equipped transport aircraft in flight. These data are transmitted by radio to the meteorological data system.

This report outlines the Australian AMDAR system presently coming into service on the Boeing 767 aircraft in the Ansett fleet. The data are telemetered using ACARS and the SITA/AIRCOM network of ground stations.

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16. Abstract *(Contd)*

Particular attention is paid to the indicator of turbulence. Because an aircraft flying through a given gust may encounter very different vertical accelerations depending on aircraft mass, airspeed and altitude, it is proposed that the AMDAR system compute the derived equivalent gust velocity from the aircraft acceleration and other parameters, and that this be used as an indicator of turbulence. Severe turbulence corresponds to derived equivalent gust velocities in excess of 9 m/s.

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